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On measurement facilities in packet radio systems*

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ABSTRACT

The growth of computer networks has proven both the need for and the success of resource sharing technology. A new resource sharing technique, utilizing broadcast channels, has been under development as a Packet Radio system and will shortly undergo testing. In this paper, we consider that Packet Radio system, and examine the measurement tasks necessary to support such important measurement goals as the validation of mathematical models, the evaluation of system protocols and the detection of design flaws. We describe the data necessary to measure the many aspects of network behavior, the tools needed to gather this data and the means of collecting it at a central location; all in a fashion consistent with the system protocols and hardware constraints, and with minimal impact on the system operation itself.

INTRODUCTION

This paper is primarily concerned with the unique measurement aspects of Packet Radio Systems as regards network evaluation, and considers the design of a set of measurement facilities, the development of data gathering techniques within the framework of the system design and the use of these measurements to evaluate the system performance and its operational algorithms.

The need for sharing of computer resources by organizing these resources into computer networks has been long recognized[1] and the feasibility of constructing such networks has been demonstrated by many successfully operating network systems. Perhaps the most prominent example is the ARPANET,[2] which utilizes the technique of packet-switching, appropriate for bursty computer network traffic, thus achieving better sharing of the communication resources.

The ARPANET emerged in 1969 as the first major packet-switching network experiment; since the essence of an experiment is measurement, and in line with Hamming's observation that "it is difficult to have a science without measurement", considerable care was taken from the beginning in the design and development effort to include the tools necessary and appropriate to satisfy the many measurement goals. As a result of well designed experiments on the ARPANET using these tools, valuable insight has been gained regarding the network usage and behavior.[3]

The Packet Radio System is another yet different example of a computer resource sharing network.[4] It is being developed by the Advanced Research Projects Agency in order to demonstrate the applicability of the packet radio concept in organizing computer resources into a computer communications network. It is this packet radio network which is of concern to us in this paper. The network is currently in its design phase,* and, as was the case with the ARPANET, care is being taken to include the ability to measure network behavior. UCLA is in charge of this measurement effort.

This concern for measurement is due to several factors. Firstly, these measurements provide a means to evaluate the performance of the operational protocols employed and the identification of their key parameters. Moreover, this realistic observation of the system behavior will assist in the validation and improvement of existing analytical models devised to study some of these operational schemes, such as the access modes and routing strategies.[5,6] Secondly, these measurements will allow for the detection of system inefficiencies and the identification of design flaws such as the inadvertent creation of a deadlock condition.[7] Thirdly, measurement facilities and data, when used to improve network design, are a valuable feedback process in which design deficiencies are detected and subsequently corrected. Wire networks differ from radio networks mainly in the omni-directional broadcast nature of the communication and consequently the protocols employed; therefore, it calls for new approaches in the design and implementation of the measurement facilities and their use.

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* A preliminary demonstration of the system is under way. A prototype network is being set up in the Palo Alto, California, area.

In the following section, we present an overview of the packet radio system concepts and a brief description of the currently specified operational procedures. In a later section, we describe the network measurement facilities which consist of the measurement tools and the techniques for data collection. In the last section, we identify and discuss in some detail the desirable measurement functions to satisfy the need for validation and performance evaluation outlined above.

THE PACKET RADIO SYSTEM

Several papers have already appeared in the literature which describe the packet radio concept and discuss many of the issues involved in the system design.[1-5,8-10] In this section, we briefly describe these system components and operational procedures necessary to understand the measurement considerations presented below.

There are three basic functional components of a packet radio system:

(i) packet radio terminals—these are the sources and destinations of traffic on the packet radio network.

(ii) packet radio stations—these function as S/F switches for local traffic and as interfaces between the broadcast system and other computers or networks. Also, they perform directory, monitoring and control functions for the overall system, and they play a central role in that all traffic passes through the station, i.e., we have a centralized network.

(iii) packet radio repeaters—their function is to extend the effective range of terminals and stations by acting as Store-and-Forward relays.

The repeater, which has been developed by Collins Radio and is called a packet radio unit (PRU), consists of a radio transceiver and a microprocessor. The function of the PRU is to receive and transmit packets according to dynamic routing and control algorithms specified by the station. For simplicity and uniformity of design, the PRU is used as the front-end of terminal devices and of stations, interfacing them with the radio net. In Figure 1 we show an oversimplified picture of the PRU identifying its various sections: the radio transceiver, the store-and-forward software, the control process, and the measurement process.

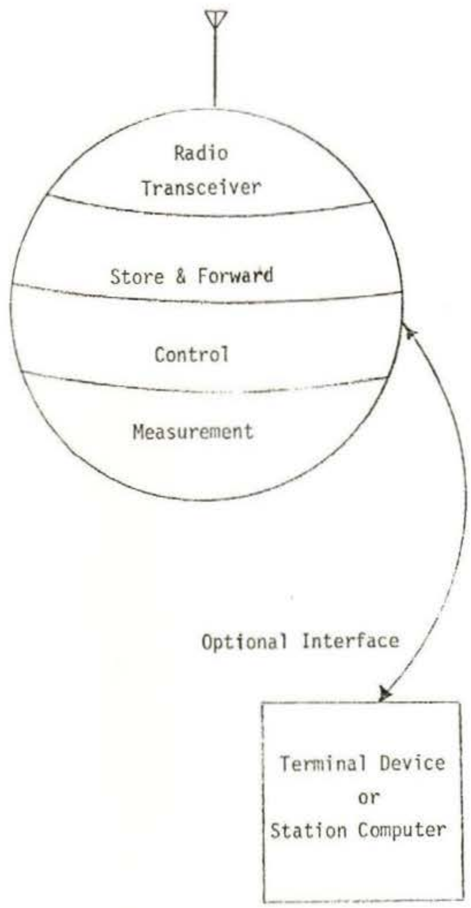

Figure 1—The packet radio unit

In this initial system, the terminals, stations and repeaters are linked together by a single broadcast channel using omni-directional antennas. The repeaters do not determine routes. All the routing computations are performed by the station. A hierarchical routing algorithm is used which makes the routing in the broadcast network resemble routing in a point-to-point network by forming a hierarchical tree structure. This structure is constructed by having the station assign to each repeater a label which defines its position in the tree. A packet is routed along the path determined by the tree, requiring the packet header to contain a string of appropriate repeater ID's, or labels. Thus, neighboring repeaters hearing the broadcasted packet but not on the determined path will reject the packet rather than relay it. However, this algorithm is flexible in that it allows the repeater to seek an alternate route for a packet when a path seems to be blocked. Moreover, the station with its monitoring procedures can dynamically restructure the tree by relabeling any of the repeaters in response to component failures or traffic congestion.

In order to achieve reliable packet transport, acknowledgment procedures are required. There are two types of acknowledgments; the end-to-end acknowledgments (FTE) between end devices, and hop-by-hop acknowledgments (HBH) between repeaters.[6] Except for the last hop on a packet's route, HBH acknowledgments are passive in that the relaying of a packet over a hop constitutes an acknowledgment of the transmission over the previous hop; this "echo acknowledgment" is due to the omni-directional broadcast property. At the last hop, an *active* HBH acknowledgment must be generated.

MEASUREMENT FACILITIES

Several factors exist in the packet radio system which do not allow for a simple transfer of ARPANET-like measurement facilities to a packet radio network. Although the latter utilizes the same technique of packet-switching, the packet radio concept is unique in the constraints it places on all system operations and the measurement effort in particular.

The radio broadcast nature of transmissions is such that the transmission of measurement data not only introduces overhead over its own path, but causes transmission interference at neighboring repeaters within hearing distances and creates additional overhead on those PRU's activities. Moreover, the desire to keep the components small and portable, as well as the limited speed of the IMP's CPU within the PRUs, place significant constraints on the measurement facilities and their usage. The available storage is extremely limited and the overhead placed on the PRU's CPU is of utmost importance in evaluating the feasibility of a measurement tool and of the collection of data in support of a measurement function. As the operational protocols of the net are different from wire nets, the measurement functions devised to support the evaluation of their performance are unique. Thus, the measurement effort consisted of identifying the measurement functions (as described in the following section) and devising the measurement facilities required to support those functions under the constraints that the system imposes. The development of the tools was an iterative design process seeking a balance between supporting the measurement functions and satisfying the system constraints, as well as making sure that the network communication protocols allow the implementation and proper functioning of those tools.

In this section, we describe the various types of statistics desired in the Packet Radio Net,* the traffic sources required in measurement experiments and the techniques available for measurement data collection. We shall postpone until the next section the detailed list of the quantities that will be measured by each of the types of statistics (tools).

* These types of statistics, as well as traffic generators, which have been widely used in ARPANET measurement experiments, will differ significantly from those of the Packet Radio Network in regards to the specific quantities gathered and the means of collecting them at a central location.

Cumulative statistics (Cumstats)

As its name suggests these consist of data regarding a variety of events, accumulated over a given period of time, and provided in the form of sums, frequencies and histograms. We shall distinguish between those data collected at the PRUs (PRU based Cumstats) and those collected at the end devices (the end-to-end Cumstats). The PRU based Cumstats provide information about the *local* environment and behavior such as traffic load, channel access, routing performance, and repeater activity. Conversely, end-to-end statistics collected at network sources and sinks, that is stations and terminal devices, will reflect more global network behavior such as user delays and network throughput.

Trace statistics

The trace capability allows one to literally follow a packet through the network, and to trace the route which it takes and the delays which it encounters at each hop. In the ARPANET, selected IMPs gather data on packets to be traced (which may include any packet) and send this data to the collection point as a new packet. In the packet radio network, however, the collection of trace data at the repeaters is prohibited by the limited size of storage in the PRU. To overcome this problem, we have introduced a new type of packet called the Pickup Packet.* These packets are generated with an empty text field by traffic generators at end devices. As these packets flow normally in the network according to the transport protocols, selected repeaters will gather the trace statistics and will store them within the text field of the pickup packets themselves.

Snapshot statistics

Snapshots give an instantaneous peek at a PRU, showing its state at that moment with regard to buffer assignment and queue lengths. (In the ARPANET, which is a decentralized network in which each node contains routing algorithms and data, snapshots also include routing related information; in the Packet Radio Network, such information is available at the station). Changes to appropriate station tables will be time stamped and collected as the station's snapshot function.

Artificial traffic generators

Traffic sources

The creation of streams of packets between given points in the net, with given durations, intervals,

* The notion of the pickup packet was first suggested by H. Opderbeck.

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